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TWO DESTRUCTIVE DEFOLIATORS OF LODGEPOLE PINE IN THE YELLOWSTONE NATIONAL PARK

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INTRODUCTION

During the years 1921 to 1925 large areas of lodgepole pine (*Pinus contorta* Loud.) in the upper valley of the Madison River in northwestern Wyoming and southwestern Montana were killed from the defoliation caused by two species of larvae. (Fig. 1.) One, which may be called the lodgepole needle tier, is the larva, or caterpillar, of a small moth belonging to the genus Argyrotaenia of the family Tortricidae; the other is the larva of a small sawfly (*Neodiprion burkei* Middleton) of the hymenopterous family Tenthredinidae, and may be called the lodgepole sawfly.

Part of the area infested, about 34,000 acres, is within the Yellowstone National Park, and the remainder, about 46,000 acres, is within the Madison National Forest. Practically all the timber on 4,480 acres in the park and on 7,680 acres in the forest is dead, while that on 8,960 acres in the Park and on 10,880 acres in the forest has been

[1] The injury caused by the needle tier and the sawfly was reported in 1923 by Chief Ranger S. T. Woodring, of the Yellowstone National Park. At the request of Superintendent H. M. Albright, a preliminary investigation of the trouble was made in July, 1924, by F. C. Craighead and J. C. Evenden, of the Bureau of Entomology. Later in the year a power sprayer and two experienced men were borrowed from the section of gipsy moth and brown-tail moth investigations, and control work was carried on by the National Park Service under the direction of J. C. Evenden. The writer spent the field seasons of 1925, 1926, and part of 1927 studying the infestation and supervising control work. W. D. Edmonston assisted in the investigations of 1927. The photographs for Figures 2; 4 A, B.; and 7, A, B, D, E, F, are by J. E. Patterson, and the drawings for Figures 5 and 8 are by W. D. Edmonston.

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severely defoliated and has suffered considerable loss in the death of many trees, as well as in the retarded growth of many others. The timber on the remaining 48,000 acres received very little defoliation and suffered practically no loss in trees or growth.

ALTITUDINAL RANGE

Although there is a continuous forest of lodgepole pine at elevations ranging from 6,500 to 8,000 feet, all the serious infestations have been confined to the floor of the valley of the Madison River, between 6,500 and 6,800 feet above sea level. Slight infestations occur in the forests above 6,800 feet, but so far these have caused no appreciable damage.

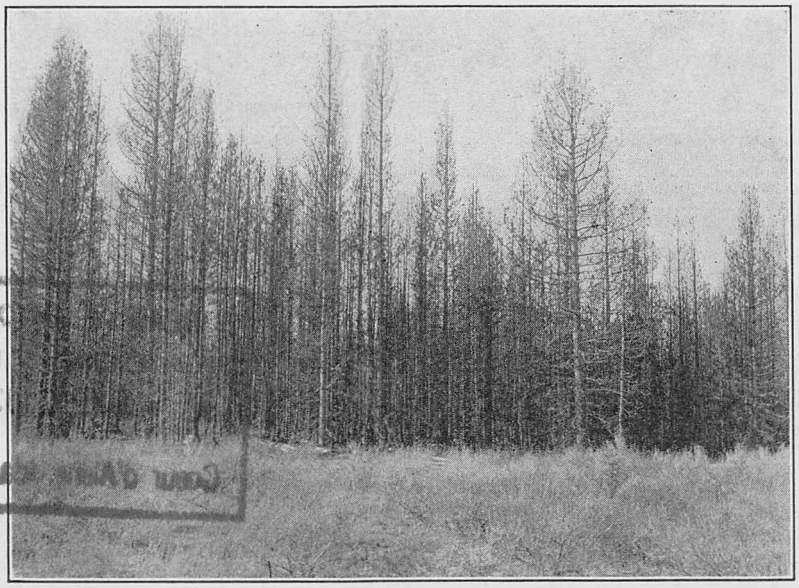

FIGURE 1.—Lodgepole pine near West Yellowstone, Mont., killed through defoliation by the lodgepole needle tier and the lodgepole sawfly

CHARACTER OF THE INFESTATION

A certain amount of infestation is found throughout the entire upper basin of the Madison River, but the heaviest infestation occurs in spots. Killed trees make up areas from 1 to 3 miles long and from one-half to 1 mile wide, which occur here and there as islands of brown or blackish-gray in a sea of living green.

The heavy infestation also moves from place to place. One year the trees in a certain area will be brown from a needle-tier infestation, and the next year the infestation will be several miles away.

Some areas, in which all the foliage appears brown and dead by autumn of one year, become green and look very well by the summer of the next year.

All observations indicate that unless the needle tier and the sawfly work together the trees are not killed. During 1924 and 1925, after the sawfly epidemic had subsided, the needle tier caused many

trees to look absolutely brown and dead. Most of these trees, however, produced new foliage the succeeding years and looked fairly well in 1927. When both species attack the same tree, however, the injury is more severe and most of the trees die. Possibly this is because the defoliation is accomplished more rapidly, and the leaves have so little time to function that sufficient material for the next season's growth can not be manufactured and stored.

Many of the larger trees of the older growth have withstood the defoliation, while those of the second growth have been killed. In some portions of the area, however, the destruction has been complete.

NATURE OF THE INJURY

The needle tier works mostly on the needles of the current year's growth, but the sawfly eats the older needles. The injury varies in severity. In the least severe attacks only a few needles are tied together and destroyed by the needle tier, or only a few of the older needles are eaten by the sawfly. In its severest form, however, the injury consists of a total destruction of the leaf surface of the tree. A single complete defoliation is a serious injury to a lodgepole pine. Some trees which have been completely defoliated die the following year; others live for several years and are apparently able to survive several more or less complete defoliations.

TYPE OF FOREST INJURED

The forest where the injurious defoliation occurs is a second growth of almost pure lodgepole pine that came in on the nearly level valley floor after a heavy fire about 50 years ago. The trees stand close together and appear of even age, although in some parts of the area larger trees belonging to the older stand are scattered among the smaller trees.

Mixed with the lodgepole pine, usually along the banks of the streams, especially the Madison River, are a few scattered whitebark pine, *Pinus albicaulis* Engelm., a few alpine fir, *Abies lasiocarpa* (Hook.) Nutt., and a few Douglas fir, *Pseudotsuga taxifolia* (La Marck) Britt.

The forest appears to have been in very good condition before the defoliations took place. There was less bark-beetle infestation than is usual in the average lodgepole forest of the northern Rocky Mountain region, and no evidence was found of the occurrence of any other injurious factor during the preceding 10 years. So far as could be determined, the defoliating insects are the sole primary cause of the death of the trees.

THE LODGEPOLE NEEDLE TIER

IDENTITY

The lodgepole needle tier has been identified by taxonomists as the pine tube moth or pine tube builder of the East (*Eulia*) *Argyrotaenia pinatubana* Kft. There are some important differences in the life history and work, however, which cause the writer to believe that the needle tier may possibly be a different and undescribed

species. According to Forbes (*2*),[2] Frost (*4*), Hartzell (*5*), Packard (*7*), Peirson (*8, p. 96–97*) and Wells (*10*), the pine tube builder pupates in the tubes of needles on the tree and passes the winter there. The needle tier always abandons the tube and goes to the ground to pupate and pass the winter. Comstock (*1, p. 643*), Forbes (*2*), Frost (*4*), Packard (*7*), and Peirson (*8, p. 96–97*) say that the tube builder feeds by biting off the tips of the needles which form the tube. The needle tier, however, does not do this but feeds on the parts within the tube, leaving the outer parts to form the tube. Frost (*4*), Hartzell (*5*), Packard (*7*), and Wells (*10*) say that the tube builder has two generations a year. The needle tier has but one. None of the writers on the tube builder say that the first-stage larva is a needle miner; the first-stage larva of the needle tier always is a miner. Frost (*4*) says it is suspected that the eggs of the tube builder are laid singly. The eggs of the needle tier are laid in groups.

ECONOMIC IMPORTANCE, DISTRIBUTION, AND FOOD PLANTS

There is no question but that the needle tier can cause large areas of lodgepole pine to turn brown and look dead. In severe infestations practically all the needles are tied into tubes which fall from the tree, and the next spring the tree is bare. The buds, however, are usually not injured, and the tree leafs out again. This explains why trees have lived after being defoliated several times in succession. The writer doubts that the needle tier, working by itself, ever kills any great quantity of timber. On the other hand, there is no doubt that when it occurs with the sawfly large quantities of timber are killed.

So far as the writer knows, the needle tier has not been reported from any western locality except the upper basin of the Madison River in Wyoming and Montana. In 1925, however, J. C. Evenden found similar work near Coeur d'Alene, Idaho.

The principal food plant of the lodgepole needle tier is the lodgepole pine, *Pinus contorta* Loud. Some specimens are found on the whitebark pine, *P. albicaulis* Engelm. None were found on the alpine fir, *Abies lasiocarpa* (Hook.) Nutt., the Douglas fir, *Pseudotsuga taxifolia* (La Marck) Britt., or the ground juniper, *Juniperus communis sibirica* (Burgsd.) Rydb., which occur in the area infested by the needle tier.

INDICATIONS OF INFESTATION AND CHARACTERISTIC WORK

The first indication of an infestation of the needle tier is the appearance about July 1 of short greenish-yellow mines near the tips of the needles. The entrances to the mines are on the concave sides of the needles, and are marked by small masses of brownish frass or borings webbed together. Later some of the needles are entirely hollowed out, and each has several holes in the concave side. Soon after the first molt the needle is vacated, and others are joined to it to make a tube. By this time about three-fourths of an inch

[2] Italic numbers in parentheses refer to Literature Cited, p. 19.

of the tip of the mined needle has turned brown, and it is apparent that something is injuring the tree. By August 15 the tips of the needles forming the tubes are becoming whitish, or greenish white, and fairly conspicuous. Each tube is lined with a strong, dense, papery white web and is usually occupied by a greenish larva about three-eighths of an inch long. There are entrances to the tubes through the needles at the base and at the tip. By the end of August most of the new needles have been tied into tubes (in cases of severe infestation), and much of the foliage is brown or greenish white where it has been mined. By October 1 the foliage is brownish, most of the larvae have left the needles, and the trees look dead, although fairly well covered with the brownish tubes of dead needles. (Fig. 2.)

Many of the needles fall off during the winter, and by the following spring the foliage is rather scanty. Some of the tubes still remain on the trees, however, and plainly indicate the cause of the trouble. The tubes of tied needles last for several years and are positive evidence of the work of this species.

The characteristic work of the needle tier consists of the silk-lined tube, formed of from 2 to 14 needles, which are so fed upon from the inner side that most of the needle surface is destroyed or so injured that it turns brown and dies.

A heavily infested forest looks dead and brown by October 1, as most of the needles are tied into tubes. (Fig. 3.) Very often, however, the buds are not injured, and the tree puts out a good growth of new needles the next year. Trees that had been so seriously defoliated that they looked dead each fall for several years finally recovered.

DESCRIPTIONS OF STAGES

The moth is 7 millimeters long and has a wing spread of 12 millimeters. The fore wings are light brownish gray, marked by darker brown patches and bands, and the hind wings are light brownish gray. The body is brownish gray. The coloration is protective. When the moths are seen resting on the foliage, the alternation of light and dark brown color causes them to resemble the unopened buds of lodgepole pine, which occur at the same time. (Figs. 4, A; 5, A, H.)

The egg of the lodgepole needle tier measures 1 millimeter in length and 0.65 millimeter in width. It is flat, oval, and slightly corrugated. When first laid it is about the color of the needle and is semitransparent. In a few days it becomes brownish yellow; later it is dark-centered and yellow-rimmed; just before hatching it is purplish gray, and the young larva can be seen within the shell. The eggs are laid in groups of from 2 to 30. (Figs. 4, B; 5, C.)

The full-grown larva is 12 millimeters long and 1.75 millimeters wide. It is subcylindrical in shape. The color of the body is dark green, and the legs are dark. The larva has three pairs of true legs and five pairs of prolegs. (Figs. 4, C; 5, F.)

The chrysalis is formed in a loosely-woven web or cocoon. Its length is 8.5 millimeters and its width 2 millimeters. It is subcylin-

FIGURE 2.—Twig of lodgepole pine showing most of the needles tied into tubes by the lodgepole needle tier. × ¾

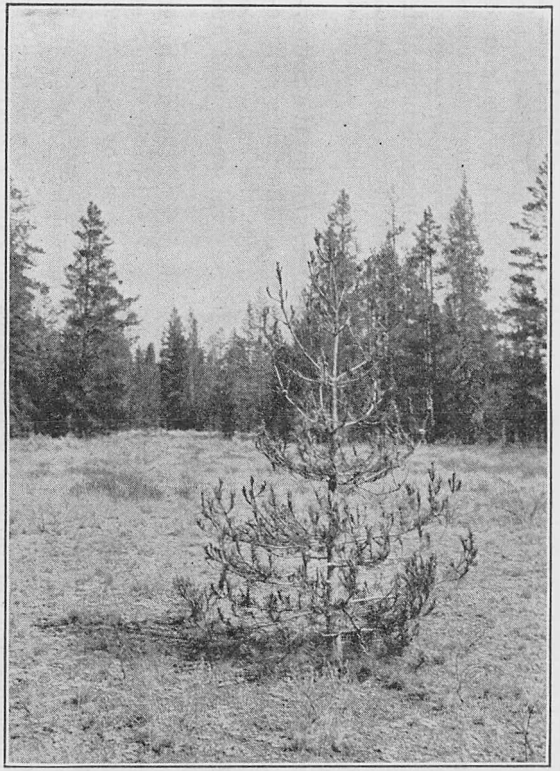

FIGURE 3.—Small lodgepole pine with most of the foliage tied into tubes by the lodgepole needle tier, showing how a heavily infested tree looks about October 1

drical, oval, rounded anteriorly, and pointed posteriorly. In color it is slightly dark brown. It has seven abdominal segments, armed dorsally with two rows of spines. (Figs. 4, D; 5, B, G.)

LIFE HISTORY

During its lifetime the individual needle tier passes through four distinct stages: The egg, the larva or caterpillar, the pupa or

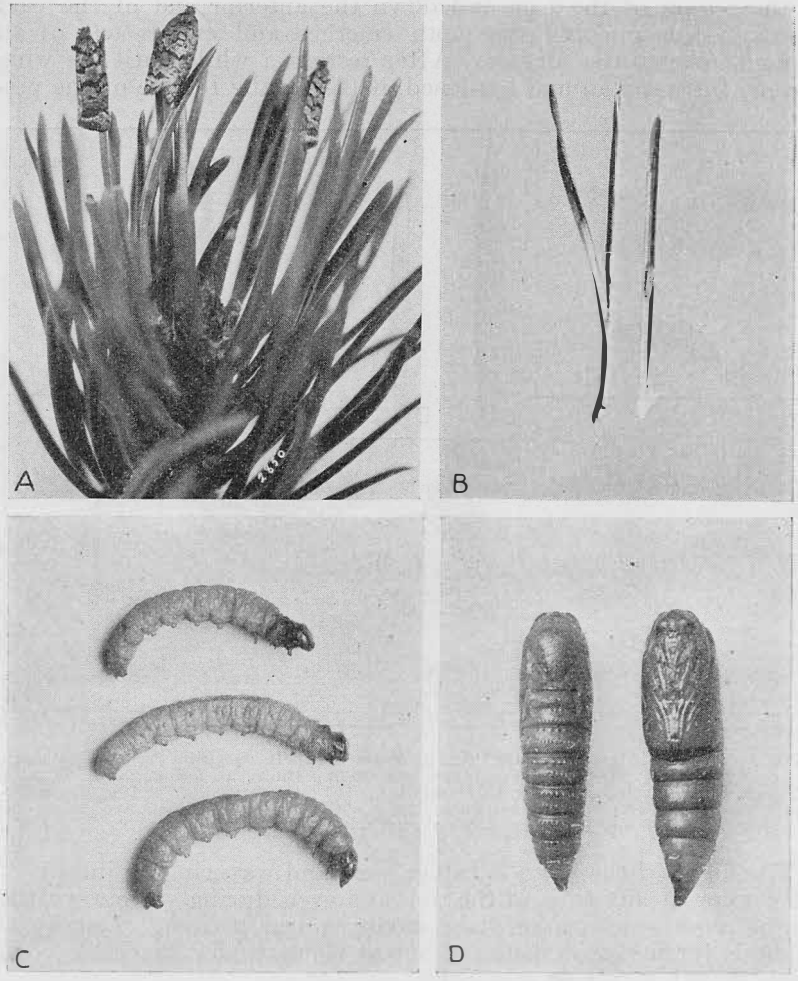

FIGURE 4.—The lodgepole needle tier: A, Moths resting on foliage, × 2; B, groups of eggs on needles of lodgepole pine, × 1; C, larvæ; D, chrysalids, × 3

chrysalis, and the adult or moth. The egg stage is passed on a pine needle. Most of the caterpillar stage is passed on the pine foliage in a tube formed in a needle or in a tube made by tying several needles together. The latter part of this stage is spent on the ground as the larva prepares to form the chrysalis. The chrysaloid stage is passed in a very slight cocoon or web among the fallen

needles on the ground. The moth passes its life on and about the foliage of the host tree. (Fig. 5.)

HABITS

The chrysalis rests quietly in its cocoon among the needles on the ground unless disturbed, when it will wriggle considerably.

The moth emerges from the chrysalis by giving a few convulsive movements of the legs and body which cause the chrysalis to split in the region of the legs and down the anterior end of the back. Through this opening the moth emerges and crawls out of the ground cover to the surface. After resting a while until the wings become fully spread and hardened, it flies to the foliage of the pine.

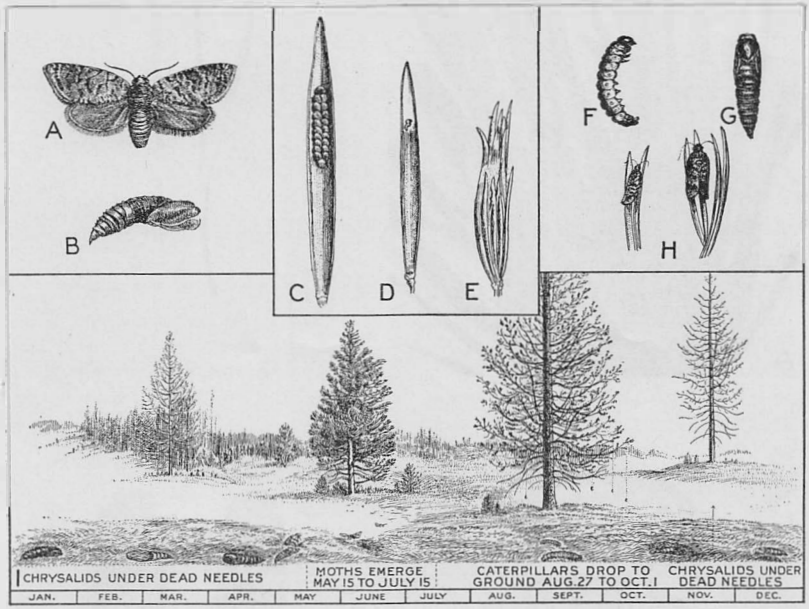

FIGURE 5.—The lodgepole needle tier: A, Moth, × 2; B, chrysalis from which moth emerged, × 2; C, eggs; D, entrance hole of first-stage caterpillar, × 1; E, tube inclosing caterpillar, × ¾; F, caterpillar, × 1; G, chrysalis, × 1¾; H, moths resting on foliage, × 1; I, seasonal history. (The appearance of a tree after the second year of infestation is shown at extreme right)

The flight of the moth is rather slow and wavering or jumpy. It may occur at any time of the day and even during stormy weather, but is more apt to take place during warm periods. Usually the flight is for no great distance, but at times, under favorable conditions, it may be for several miles.

Once on the foliage, the moth usually rests rather quietly on a twig, a bud, or a needle (fig. 4, A), with the wings folded rooflike over the body. Any disturbance will cause it to wriggle down through the needles and drop to the ground or fly away.

Mating takes place on the needles, the male and female facing in opposite directions and the tips of the abdomens touching. The wings of the female almost completely cover the male.

Soon after mating the female seeks a suitable needle and starts to lay eggs. The needle selected may be from 1 to 5 years old and on any part of the tree. Usually a needle of the lodgepole pine is selected, but eggs have been found on needles of the whitebark pine.

The eggs are laid in groups of from 2 to 30 on the concave side of a needle, the average number for 239 groups being 10.2. The eggs in the group are generally laid overlapping one another in two alternating rows near the middle of needle. Sometimes there are three rows. The overlapping of the eggs in the row and of the rows gives the group the appearance of being plaited or braided. (Figs. 4, B; 5, C.)

Hatching takes place from 7 to 10 days after the egg is laid. In hatching the larva moves around and bites a slit in the shell along the circumference where the rounded top joins the flat bottom. As soon as the slit is long enough, the larva pushes its head through the opening and by various contortions crawls out of the shell and away on the needle. An entire group of eggs will hatch in from 5 to 10 minutes.

The newly hatched larva is a vigorous crawler and is able to go from needle to needle or from twig to twig. It crawls around over the foliage until it finds a needle that suits, usually one of the current year's growth, and as a rule enters the needle on the concave side, about one-fourth inch from the tip, by biting a circular hole through the needle surface with its strong jaws and mining into the central tissue. The entrance hole is marked by a mass of light-greenish borings. (Fig. 5, D.)

The caterpillar spends from two to three weeks in the needle, mining out and feeding on all or part of the interior. The tip is usually mined first, and then the part toward the base. At least one other hole in addition to the entrance is made in the needle surface, on the same side as the entrance, and usually toward the tip of the needle. The mine inside the needle forms a tube which occupies the entire mined part of the needle. This tube is lined with a papery white, closely woven web.

As soon as a caterpillar has completed the growth of its first instar, which is about the time it has finished with one needle—having mined out a third, a half, or the whole of the interior—it reaches out and spins a web which draws together two or more needles to form a new tube. (Fig. 5, E.) This tube is also lined with a papery white web. Usually there is an opening at the upper end and also one at the lower so that the caterpillar can leave the tube quickly if disturbed. It will wriggle rapidly down through the needles and hang on a long strand of web in its effort to escape.

Feeding takes place within the tube, the parts of the needles toward the tube being eaten. As the caterpillar becomes larger, the tube is extended farther down the needles, sometimes to the base. Other needles are drawn to those already used, and the tube may be enlarged to include as many as 12 or 14 needles. Usually the more needles used to form the tube, the less each needle is eaten. Sometimes the first tubes are formed from the needles of the preceding year's growth, but the later tubes are nearly always formed from the new growth. Often a caterpillar will abandon one tube and

form another. This probably holds true also for the first-stage caterpillars in the individual needles. Late in the season full-growth caterpillars are sometimes seen reaching out from their tubes and making a final meal off near-by needles.

After six to eight weeks spent in the tube, the caterpillar is full grown and drops to the ground by a strand of web. Then, crawling down into the mat of old needles which forms the top of the forest floor, it spins a very loosely woven cocoon, in which it forms its chrysalis. The cocoon is attached to old needles, old cones, dead twigs, or other débris. In from three to five days after the cocoon is spun the chrysalis is formed, and the insect is prepared to spend the winter.

SEASONAL HISTORY

The needle tier starts activity in the spring with emergence as a moth from the brown, mummylike chrysalis which has lain all winter on the ground among the top layers of fallen needles. (Fig. 5, I.)

Normally emergence occurs from May 15 to July 15. In 1925 moths were common from June 11 to July 9; in 1926 there was a heavy flight on May 28, and moths occurred in fair numbers until June 28; in 1927 emergence took place principally between June 10 and July 15.

Temperature appears to control the time of emergence. Chrysalids kept in a warm laboratory produced moths as early as November 20, and those taken from under the snow on March 3 and placed in the laboratory produced moths in from 14 to 18 days.

The great majority of the eggs are laid between June 15 and July 10, and most of them hatch between June 20 and July 10. Most of the young caterpillars are in the needles by July 10. They are found entering, however, from June 15 to July 25.

Some caterpillars start forming tubes of several needles by July 12. They become full grown and drop to the ground as early as August 27, practically all of them being on the ground by October 1.

The earliest date on which a chrysalis has been found is September 10. Chrysalids are found in numbers by the end of September, and some overwintering ones have been discovered as late as July 1.

There is a single generation of the needle tier each year. The individual insect spends about 2 weeks as an egg, 2 months as a caterpillar, 9 months as a chrysalis, and 2 weeks as a moth. (Fig. 5.)

NATURAL CONTROL

During the three years the needle tier was under observation at West Yellowstone natural enemies did not appear to be an important factor in its ecology. A few parasites were reared, but no predators or bird or mammal enemies were seen. Fungous and bacterial diseases were not observed, but about 3 per cent of the larvae in the tubes were found dead and shriveled. Climatic conditions are not of the best at West Yellowstone, but eggs, larvae, and moths appear to be able to withstand freezing temperatures, heavy rains, hail, and snow without serious injury. The larvae still work in the tubes when the night temperature is as low as 22° F. and when there are several inches of snow on the ground. The chrysalids overwinter

in the needles on the ground, where the temperature goes down to 20° to 50° below zero, and where there is considerable freezing and thawing before emergence takes place.

PARASITES

Two species of ichneumon parasites were reared in fair numbers from the needle tier. One species, an undescribed species of Campoplex, when about ready to pupate leaves the full-grown larva of the needle tier and spins a rather fuzzy white cocoon among the needles. (Fig. 6.) The second, a species of Phaeogenes, remains in the larva of the needle tier and pupates in the needle tier's chrysalis. Apparently only one individual of either parasite is capable of developing in a single larva of the needle tier.

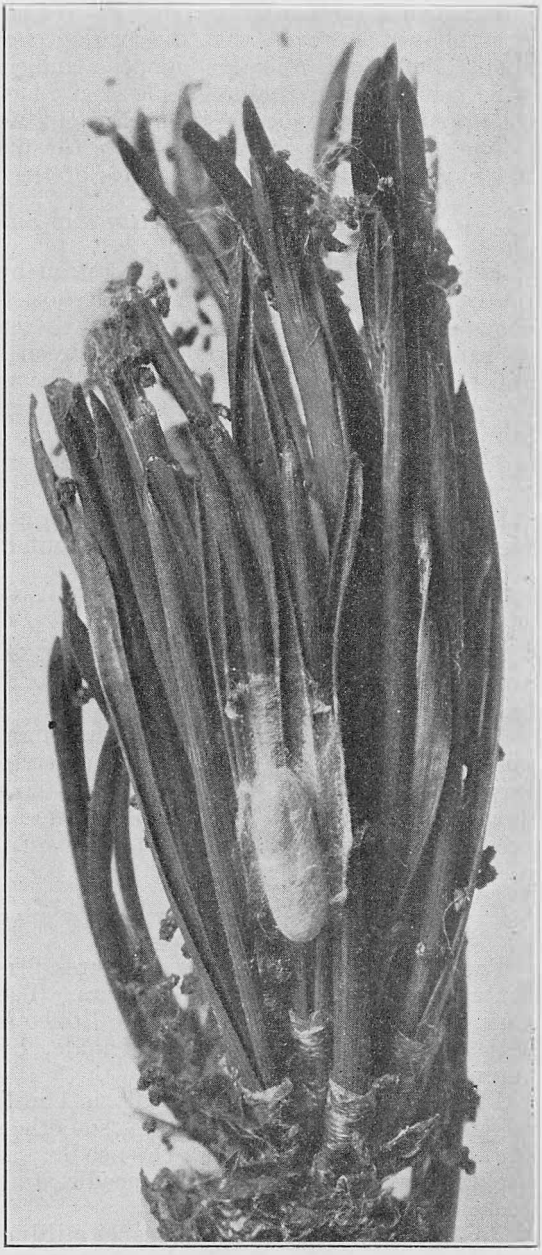

FIGURE 6.—Cocoon of an ichneumonid parasite of the lodgepole needle tier. × 3

THE LODGEPOLE SAWFLY

IDENTITY

The lodgepole sawfly (*Neodiprion burkei* Middleton) was recently described under that name by Middleton (*6*) as a new species. It belongs to the family Tenthredinidae. Several species of this genus are reported as enemies of coniferous trees in various parts of the United States.

IMPORTANCE, DISTRIBUTION, AND FOOD PLANTS

Owing to the fact that the lodgepole sawfly practically disappeared during the season of 1925, its relative importance and that of the lodgepole needle tier in killing the timber

in the Madison River Basin was not determined. Apparently very little lodgepole pine has died since the disappearance of the sawfly, although the defoliation by the needle tier has continued. This may indicate that the sawfly was the more injurious species of the two. It is known, however, that the two species working together killed about 12,000 acres of lodgepole pine timber.

So far as known, the lodgepole sawfly has been reported only from the upper basin of the Madison River in Montana and Wyoming.

The lodgepole pine appears to be the principal food plant, but a few eggs were found in the needles of the whitebark pine.

INDICATIONS OF INFESTATION AND CHARACTERISTIC WORK

The first indication of an infestation by the lodgepole sawfly is the occurrence of the characteristic shoe-shaped egg pockets in the edges of the needles. Later many of the needles will be surrounded by groups of light-striped, grayish-green larvae with brown heads and black eyes. By autumn most of the needles are eaten down to the sheaths and the large larvae are solitary. During the winter the brown cocoons are found on the ground among the top layers of old needles, and some needles remaining on the tree show the characteristic egg pockets.

Four or five years after an infestation is past, a few needles showing the egg pockets can usually be found, and cocoons can nearly always be found on the ground.

The most characteristic work of the sawfly is the group of shoe-shaped egg pockets made along the edge of the needle. (Figs. 7, A; 8, C.) Usually one false or trial pocket is made in a needle before an egg is laid. Then from 2 to 11 pockets are made, and an egg is laid in each.

In feeding, the small larvae eat irregular patches of pulp from the outer surface of the needles, sometimes stripping off all the pulp and leaving only the midrib. The larger larvae eat the entire needle down to the sheath. Usually most of the feeding is done on the older needles, but larvae will feed on the growth of the current year when the older needles are gone.

DESCRIPTIONS OF STAGES

The male lodgepole sawfly measures 6 millimeters in length and has a wing spread of 13 millimeters. The female is 8 millimeters long, with a wing spread of 17 millimeters. The male is blackish, with feathered antennae; the female, brownish, with threadlike antennae. (Fig. 8, A, B.)

The egg of the lodgepole sawfly is 1 millimeter long by 0.3 millimeter wide. It is oval in shape, smooth, shining, translucent, and slightly lighter in color than the needle. It is laid in a shoe-shaped pocket sawed in the edge of a needle, and is about the size of the pocket. (Figs. 7, A, B; 8, C.)

The full-grown larva measures 24 millimeters in length by 3 millimeters wide. It is subcylindrical in form, hairless, and wrinkled. In color it is greenish, or grayish green, with lighter lateral and dorsal stripes; the head is dark brown; and the eyes black. It has three pairs of true legs and eight pairs of prolegs. (Figs. 7, C; 8, E.)

The prepupal larva is from 7 to 9 millimeters long and from 2 to 3 millimeters wide. It is slightly curled, plump, and dark green in color. (Figs. 7, E, F, G; 8, F.)

The cocoon of the male is 8 millimeters long by 3 millimeters wide. That of the female is 10 millimeters long by 4 millimeters wide. The cocoons are cylindrical with hemispherical ends. They are tough, parchmentlike, and dark brown. (Figs. 7, H, I; 8, G.)

The pupa is plump and varies in color from light to dark brown. The legs, wings, and antennae are free. (Figs. 7, D; 8, H.)

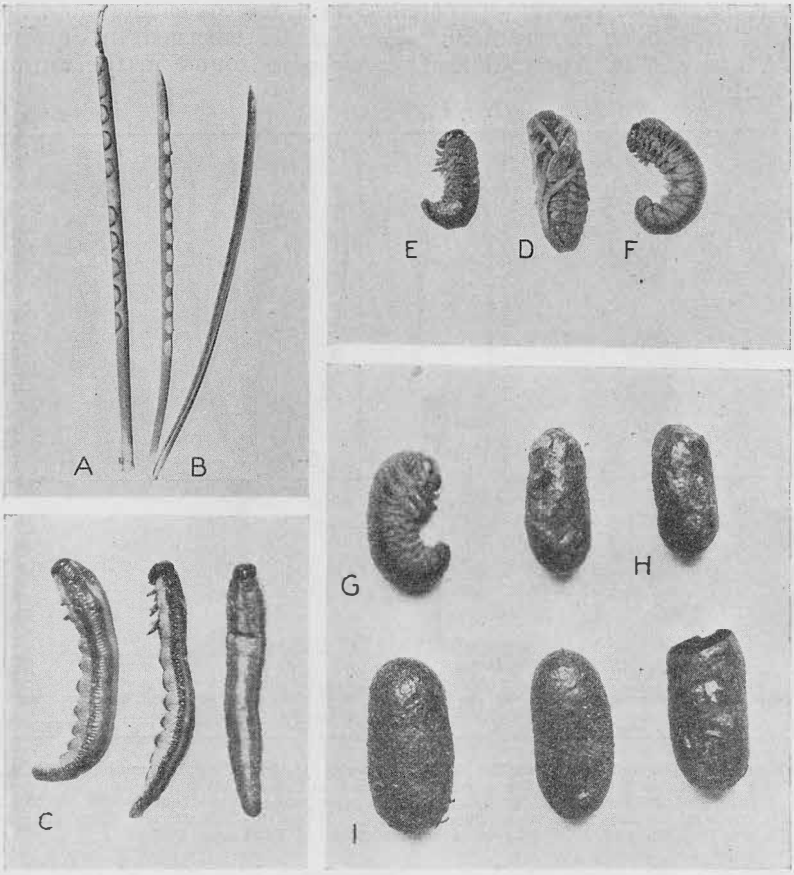

FIGURE 7.—The lodgepole sawfly: A, Egg pockets in a lodgepole-pine needle 1 year old or older, × 2; B, egg pockets in a fresh needle, × 2; C, full-grown larvae, × 1⅓; D, female pupa, × 2; E, F, prepupal larvae, × 2; G, male prepupal larva, × 2½; H, cocoons of male, × 2½; I, cocoons of female, × 2½

LIFE HISTORY

Like the lodgepole needle tier, the lodgepole sawfly passes through four distinct stages during its lifetime. The egg is laid in a pocket sawed in a pine needle by the female. The feeding and growing part of the larval stage is passed on the foliage of the pine, and the resting part in a cocoon among the needles on the ground. The pupal stage is passed in the same cocoon. The short first part of the adult

stage is passed in the cocoon, and the remainder in flying around and crawling or resting on the foliage of the pine.

HABITS

The prepupal larva rests quietly in its cocoon on the ground. It does not move when taken from the cocoon. After spending one winter or several winters in the cocoon it pupates. Temperature does not appear to have a great deal of influence on the time of pupation. Cocoons kept in a warm laboratory held over for two winters before pupating. However, they pupated several months earlier than they would have done in the field. Three males emerged in January, 1927, and one in April, 1928, from cocoons found in the autumn of 1924.

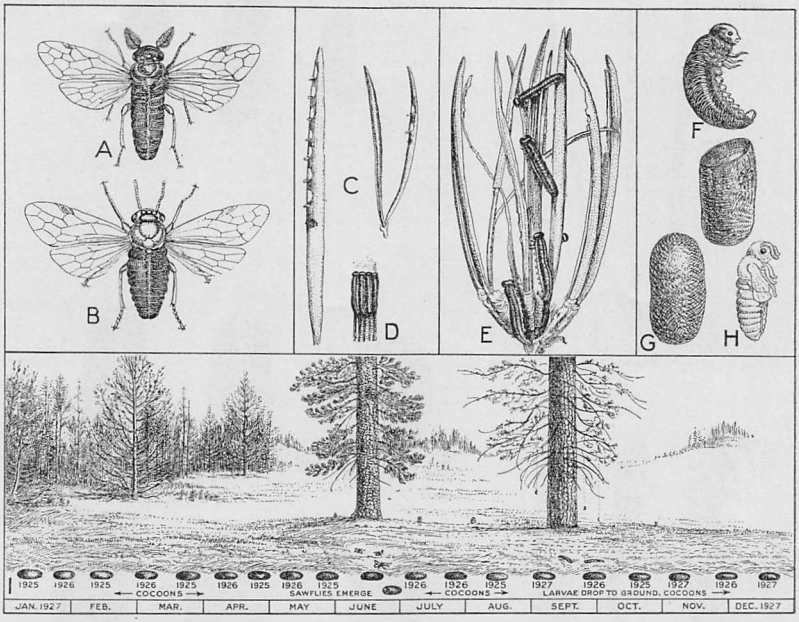

FIGURE 8.—The lodgepole sawfly: A, Adult male, × 2; B, adult female, × 2; C, egg pockets in lodgepole-pine needles, × 1½; D, young larvae feeding, × 2; E, larvae and their work, × ⅓; F, hibernating prepupal larva from cocoon, × 2½; G, cocoon, × 2½; H, male pupa, × 2½; I, seasonal history. (The cocoons found in 1926 and 1927 may have been cocoons of 1924 and 1925)

The transformation from pupa to adult takes place in the cocoon shortly after pupation, and the adult soon emerges. To do this, the adult makes a circular cut around one end of the cocoon, pushes off the separated end, and crawls out.

Soon after emergence the adult flies to the foliage of the pine, where mating and egg laying take place.

The females are not very strong fliers, and once on the foliage usually stay there unless disturbed, when they will drop rather than fly. They are not easily disturbed, and with ordinary care a pine needle on which one is resting can be detached and placed in a vial without disturbing the occupant. The males are quite active and

fly quickly. Sometimes they swarm around the trees, hovering and darting into the foliage.

Cool or rainy weather makes the adults quieter, but as soon as the sun shines they are active again. Frosty nights do not seem to cause them any serious injury.

Mating takes place on the foliage, the male and female facing in opposite directions and the tips of the abdomens touching.

Not very long after emergence, whether or not mating has taken place, the female begins to lay eggs. Placing herself on a needle, near the base and facing the tip, with her ovipositor she saws an incision in the edge of the needle. Usually the first incision appears to be a trial one, and no egg pocket is formed. She then moves up the needle a short distance and makes another incision, this time completing the egg pocket, an oblong, oval, or shoe-shaped receptacle sawed in the pulp of the needle. The opening is marked by a protruding mass of sawed pulp. When the pocket is finished an egg is deposited, and the female moves up the needle a short distance and repeats the process, taking from five to seven minutes for each egg. When the tip of the needle is reached, or when she has been disturbed in any way, she will crawl off and rest awhile before selecting another needle.

As many as 14 eggs are laid in a single needle, the average for 162 needles being 6.8. Eighty-three of the needles contained 6, 7, or 8 eggs each. Nearly all the eggs are laid in needles of the previous year's growth.

About one month after being laid the fertilized eggs hatch. Before hatching the egg swells and splits the edge of the needle over the pocket so it is very easy for the young larva to get out. All the eggs in a needle hatch at about the same time. So far as the writer could determine, the unfertilized eggs do not hatch. None of the eggs found in 1926 and 1927 hatched. Adults were scarce during these years, and probably not many eggs were fertilized.

During the earlier stages the young larvae keep very close together, usually lying longitudinally along a needle with their heads toward the tip. Often they lie so close together that, touching one another, they form a complete circular tube around the needle. In feeding they eat irregular patches of pulp from the outer surface of the needle, sometimes completely stripping off the pulp and leaving only the midrib. (Fig. 8, D, E.)

By midsummer the larvae are about half grown. They do not keep so close together as before, but start to scatter over the foliage and eat the entire needles down to the sheaths. By September 1 they are nearly full grown and about 1 inch in length. Most of their feeding is done on the older needles, but they will eat those of the current year's growth.

Rather severe weather, such as a night temperature of 24° F. in the middle of August, heavy rain, or hail, does not seem to be detrimental to the species. In 1925, however, the entire generation of feeding larvae disappeared about September 1, and none have been found since.

Just how the larva reaches the ground and forms the cocoon is not known, but it is supposed that it drops with the assistance of a strand of web. The cocoon is found unattached among the needles on the ground beneath the tree.

SEASONAL HISTORY

The sawfly starts activity in the spring by pupating in the cocoon. This occurs from the middle of May until the last of June. Transformation to the adult and emergence from the cocoon take place soon afterward. Adults are found in the field from the first of June to the middle of July. The young larvae hatch from the eggs from the middle of July to the middle of August. Until the latter date most of the larvae are gregarious, but after that they are more or less scattered. In 1925 feeding larvae were found until September 7, at which time most of them appeared to be full grown. Shortly afterward all disappeared and were not seen again. Prepupal larvae in the cocoons were found at all times of the year.

The sawfly has but a single generation each year. Part of the generation, however, remains as prepupal larvae in the cocoons for two, three, or four years before pupating, transforming to adults, and emerging. The individual insect spends about 1 month as an egg, 2 months as a feeding larva, 8 to possibly 44 months as a prepupal larva in the cocoon, 1 week as a pupa, and 2 weeks as an adult. (Fig. 8, I.)

NATURAL CONTROL

During the period the sawfly was under observation at West Yellowstone its natural enemies did not appear to be of much importance. Infestation by the species practically disappeared, however, in September, 1925, after a numerous brood of larvae had been hatched. The writer was unable to determine the cause of this disappearance. Parasites, predators, and disease were not common, and the climatic conditions were not unusual.

No egg or larval parasite was found, but an ichneumonid, a chalcid, and a tachinid were reared from the cocoons. The ichneumonid and the tachinid are solitary, 1 to each cocoon, but 30 of the chalcids emerged from a single cocoon. The percentage of parasitism is shown by the following examinations: From 101 cocoons collected June 22, 1925, 6 ichneumonids and 3 tachinids were taken; and from 99 cocoons collected September 26, 1925, 1 ichneumonid and 1 tachinid were taken.

Several times ants were seen on the foliage, capturing male sawflies, but no other predators were seen.

Birds often feed on the larvae of insects related to the lodgepole sawfly, but none were seen feeding on this species, nor had any cocoons of this sawfly been opened by small mammals, as mice, which sometimes open the cocoons of other sawflies and feed on the prepupal larvae.

In a few instances prepupal larvae in the cocoons were found dead and covered with a chalky-white fungus.

So far as could be determined, rain, hail, and freezing temperatures had no effect on the adults, eggs, or larvae of the lodgepole sawfly. Such weather occurs every month of the year at West Yellowstone.

ARTIFICIAL CONTROL

The commonly approved method of control for defoliating insects like the lodgepole needle tier and the lodgepole sawfly is the application of a poison spray to the foliage about the time the larvae are

hatching. During the seasons of 1924, 1925, 1926, and 1927 this method was followed at West Yellowstone, Mont., with considerable success.

A strip of timber about 150 feet wide on each side of the main highway between West Yellowstone and the Madison River bridge was sprayed. (Fig. 9.) In 1924 the trees around the Union Pacific Railroad station at West Yellowstone and along the first 5 miles of highway were sprayed. In 1925, 1926, and 1927 the trees along the 7½ miles of highway to the Madison River bridge and along some lateral highways were sprayed.

The cost of the spraying ranged from $6.50 to $10 per acre. The results were very good, as the strip of timber along the highway was kept green, while in many areas outside all the trees were defoliated

FIGURE 9.—Spraying to control the lodgepole needle tier and the lodgepole sawfly at West Yellowstone, Mont.

and brown. Examinations of the sprayed trees indicated that about 90 per cent of the infesting larvae were killed by the control work.

The spray formula used was that recommended by the Bureau of Entomology for use against the gipsy moth—25 pounds of powdered lead arsenate and 1 gallon of fish oil or raw linseed oil to 400 gallons of water. The work was done with a large motor-truck sprayer furnished with the regular gipsy-moth equipment of hose and Worthley nozzles, and a motor-truck water cart, used as an auxiliary water carrier.

The great disadvantage of spraying in fighting a forest insect is the impossibility of moving the sprayer through the forest to reach all the infested area. If only the trees along the highway are treated, there is a constant reinfestation each year as long as the epidemic lasts. The total cost of keeping the highway green for several years would probably be sufficient to control the entire infestation

in one year and save many trees if a suitable method of control could be found.

Two other methods of control besides spraying have been considered in connection with the needle tier and sawfly problem at West Yellowstone. One was to burn the duff beneath the trees to kill chrysalids of the needle tier and prepupal larvae of the sawfly in the cocoons before the emergence of the adults. If any insects can be controlled by this method the needle tier and the sawfly can be, because they lie in the top of the duff and not down under it, as many similar insects do.

One great difficulty with this method is to get the duff to burn at the proper time; another is to keep the fire from burning so much that it will do more damage than the insects. Light burning, as reported by Show and Kotok (*9*), has been tried a number of times but for various reasons without success. Usually the duff is so damp that it will burn only in spots, or it is so dry that many trees are severely damaged. At a conference of officials of the national park, the national forest, and the Bureau of Entomology it was decided not to try this method at West Yellowstone.

Another method of control suggested was to dust the infested area by means of an airplane. This seems to offer the most feasible method of applying a poison to a large forest area. The method has been tried in other regions against other insects and reported a success by Fracker and Granovsky (*3*). Owing to the undeveloped state of the method, some question as to its efficiency, and the difficulty of obtaining an airplane, dusting was not attempted at West Yellowstone.

SUMMARY

During the years 1921 to 1925 two species of insects defoliated and killed large areas of lodgepole pine timber in the upper basin of the Madison River in northwestern Wyoming and southwestern Montana. Part of the infested area lies within the Yellowstone National Park and part within the Madison National Forest.

One of these insects, the lodgepole needle tier, is a true caterpillar, the larva of a small brownish-gray moth belonging to the genus Argyrotaenia of the family Tortricidae. The other, the lodgepole sawfly, is a false caterpillar, the larva of a small brownish or blackish insect with four clear wings (*Neodiprion burkei* Middleton) of the family Tenthredinidae.

The larva of the needle tier hatches from an egg laid in a group on a needle in the early summer. It feeds in a tube formed first from a single needle and later from a number of needles webbed together. Most of its feeding is done on the needles of the current year's growth. It becomes full grown the latter part of September, drops to the ground, transforms to a chrysalis, and passes the winter in a slight cocoon spun among the fallen needles. In June or July it transforms to a moth which emerges and flies to the foliage of the lodgepole pine.

The larva of the sawfly hatches from an egg laid in the edge of a needle in June and feeds first on the outer pulp of the needle, later on the entire needle. Most of its feeding is done on the needles of older growth. It becomes full grown in September, drops to the ground, shortens considerably, spins a tough brown cocoon about

itself, and hibernates for one or several winters in this stage. In the spring it pupates in the cocoon and transforms to the sawfly, which emerges and flies to the foliage of the lodgepole pine.

The trees along the West Yellowstone-Madison Junction Highway in the Yellowstone National Park were kept green during 1924, 1925, 1926, and 1927 by spraying the foliage with a solution of 25 pounds of powdered lead arsenate, 1 gallon of fish oil, and 400 gallons of water. A large power sprayer was used to apply the spray. About 90 per cent of the infesting caterpillars were killed at a cost of from $6.50 to $10 per acre.

Because of the great difficulty of carrying on spraying operations away from roads and highways no attempt was made to control the infestations in the distant areas.

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